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A STRATEGY FOR MEASURING OFF-HIGHWAY TRUCK ROLLING RESISTANCES

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A STRATEGY FOR MEASURING OFF-HIGHWAY TRUCK ROLLING RESISTANCES

by

N.J. Stuart* and R.J. Kolada*

ABSTRACT

This report describes the need for a convenient method to measure the rolling resistance experienced by trucks travelling on mine haulage roads. The importance of knowing the rolling resistance produced by haulage roads is illustrated by an example of its effect on the productivity of a haulage fleet and the consequent effect on the economics of the mine.

A proposal is outlined for a resistance measuring test vehicle which is towed by a small truck and includes suggestions for both the construction of the test vehicle and the instrumentation package. Also included is a discussion on how the test data may be calibrated to predict the resistance experienced by the various types of mobile mining machinery.

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MÉTHODE POUR MESURER LA RÉSISTANCE AU ROULEMENT DES CAMIONS TOUS-TERRAINS

par

N.J. Stuart* et R.J. Kolada*

RÉSUMÉ

Dans ce rapport, les auteurs signalent le besoin d'une méthode appropriée pour mesurer la résistance au roulement des camions qui se déplacent sur les voies de roulage des mines. L'importance de connaître la résistance au roulement produite par les voies de roulage est illustrée par un exemple afin d'en démontrer les effets sur la productivité d'un ensemble de véhicules de remorquage et les conséquences sur la rentabilité de l'exploitation minière.

Le rapport présente les grandes lignes d'une proposition relative à la construction d'un véhicule d'essai remorqué par un petit camion et des suggestions concernant la construction du véhicule et de l'appareillage d'essai. Le rapport porte également sur la manière d'étalonner les données d'essai de façon à prédire le niveau de résistance des différents types de machines mobiles de mine.

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INTRODUCTION

Rolling resistance is often the most important external factor that limits off-highway truck performance. At a mine where material transportation is accomplished by trucks the profitability of the mine is very sensitive to their performance and is therefore also sensitive to rolling resistance of the haulage roads. As an example, Fig. 1 shows the effect of rolling resistance at a typical mine (1). The upper graph is a plot of the time taken for trucks to complete the cycle of moving material from the point of mining to the processing plant and back again. The lower graph shows the effect of cycle time on the cost of hauling each ton of material. As illustrated, the effect of changing the haul road resistance by 4% produces a 50 cent change in the haulage cost per ton, which is 25% of the total cost.

Considering the dramatic effect that rolling resistance can have on the economics of a mine it is surprising that a simple method of measuring rolling resistance does not yet exist. This report therefore proposes a simple standard measuring device for rolling resistance. One which will reflect the actual driving conditions at time of test as a realistic value for a typical piece of equipment, but which could be further calibrated to give a more accurate value for specific truck/tyre combinations.

EXISTING METHODS OF MEASURING ROLLING RESISTANCE

MINE SITE METHOD

Current methods for determining mine site rolling resistances involve measuring the force needed to tow a truck around the haulage route. In general this requires two trucks since one is needed to pull (3). To use this method on a regular basis to, for example, monitor mine site rolling resistance or test a road surfacing material, would almost certainly be unacceptable in terms of cost. Indeed this method is not in regular use anywhere in Canada. To make the cost of measuring more acceptable and easier to perform a single small vehicle capable of measuring rolling resistance would be ideal.

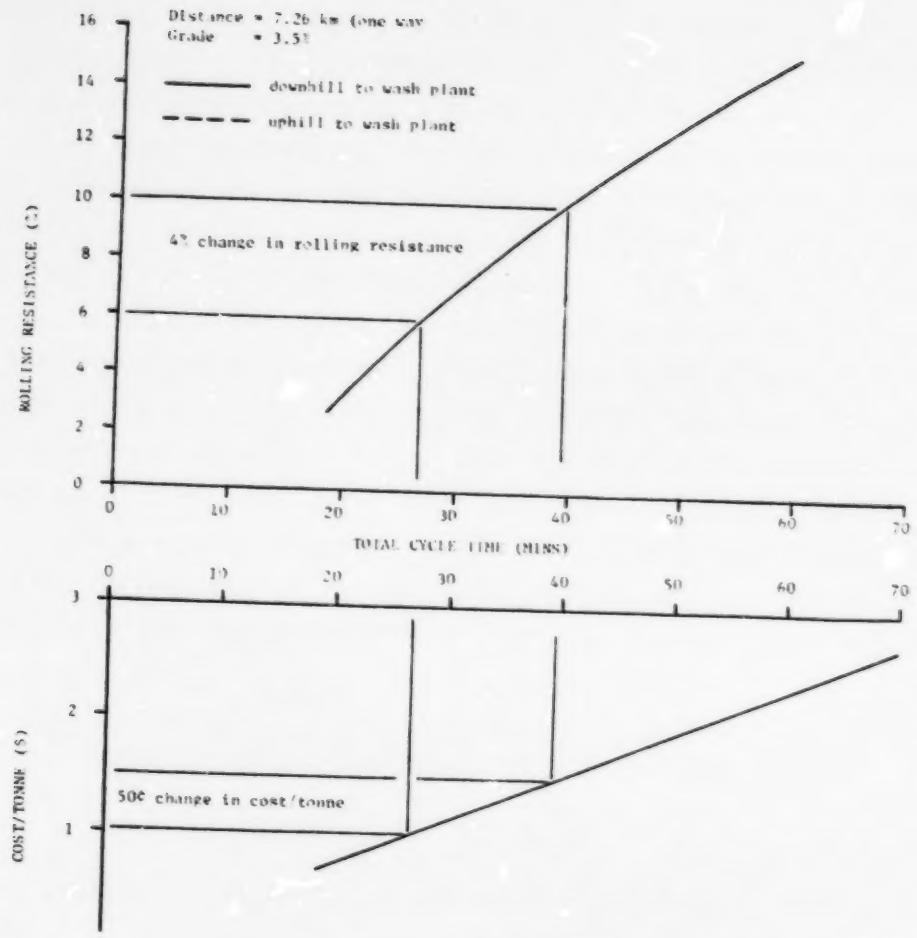

Fig. 1 - The effect of rolling resistance on the cost of haulage

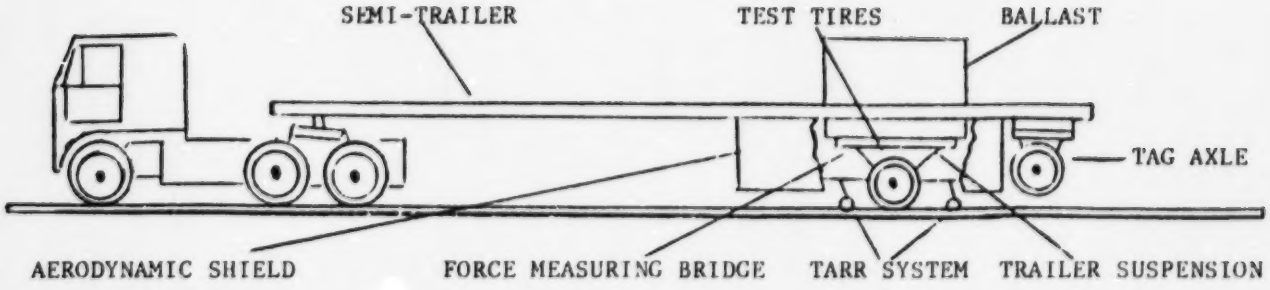

Fig. 2 - Transport Canada, single vehicle, tyre rolling resistance measuring system

HIGHWAY METHOD

In collaboration with Transport Canada, Davis Engineering constructed a single vehicle rolling resistance measuring system (1). The system consisted of a 45 foot flat bed trailer, as shown in Fig. 2, towed at a normal highway speeds. The outputs from six load cells, two inclinometers and a tangent angle-rolling radius device were used to automatically resolve the rolling resistance forces, rolling radius, bearing moments and the vertical and transverse tyre loads. Tyre pressure and cavity temperature were also measured and the outputs from all these sensors were automatically recorded by an on-board data acquisition system. A photographic method was used to measure body slip angle.

The primary purpose of the rig was to measure TYRE rolling resistance but in order to achieve this it is also necessary to measure the resistance produced by the road conditions. The resistance due to tyre flexing is a significant proportion of the total resistance in well paved highway conditions. However in the mine site situation it is likely that the resistance due to tyre flexing will be small (compared to the resistance arising from the road conditions) and will not vary significantly for different tyres or conditions. Consequently this type of system may be rather more elaborate that is necessary for mine site applications. However, it is important to note from this work that the technology exists to measure the factors described above and that this instrumentation has been thoroughly tested.

PROPOSED MINE ROADWAY ROLLING RESISTANCE MEASURING UNIT

It is suggested that the ideal system for future measurement of mine rolling resistances would consist of a towable buggy with a compartmented water tank for ballast. The buggy would be towed by a small vehicle capable of negotiating mine site terrain such a Jimmy, Bronco or Cherokee for purposes both of performing the test and for transportation to the mine site. At this stage it is believed that a two wheel buggy would provide the best solution. It is desirable to have a high axle weight (thus the fewer wheels the better) but that a single wheel device would tend to complicate the towing arrangement and add high torques to the towing force transducer.

The components of the buggy would thus be:

a. An axle with suspension and two wheels, probably salvaged from a large highway vehicle, and equipped with wheels that have off road tyres.

b. A compartmented water tank to increase the axle weight by a known amount and to enable the weight to be balanced directly over the axle. By using a water tank it would also be unnecessary to transport the ballast to and from the mine.

c. A towing bar/force transducer; (for reasons of placing the centre of gravity slightly forward of the axle and for the eventual testing of an automated roadway inclination measurement system, a relatively long tow bar would seem desirable).

d. A data acquisition system: in the initial trials the polycorder would be suitable; although at a later date the system can be expanded using similar equipment to that used by Transport Canada (1).

It is estimated that initially the only major cost would be acquiring a suitable towing vehicle and for the fabrication of the buggy.

THE USE OF THE BUGGY

The first and most important task is to acquire data from a wide variety of western Canadian coal and oilsands producers of measured rolling resistance with auxiliary data such as weather, tyre penetration, maintenance policy of the road and perhaps some well chosen soil mechanics parameters. The later might include property determination tests such as cohesion, adhesion and friction tests as well as index test such as Agterberg limits or penetrometer tests.

The significance of the data would be threefold. Firstly, an operator using realistic rolling resistance can, through the use of e.g. the CANMET/NRC mathematical model, more accurately predict cycle times and thus haulage requirements. Secondly, the additional data will allow an economic model to be built on the effect of roadway maintenance on overall haulage economics, allowing optimisation. Thirdly it is a necessary precursor to meaningful research into rolling resistance; it would reveal the mine types

for which it is most critical and provide the initial clues as to the mechanical nature of the energy absorbing processes.

THE MODELLING PROBLEM

The buggy is to be thought of as a physical model of half a truck. Every effort is to be made to make the processes around the model tyre resemble those of the full size problem. The first consideration is geometry. The tyre must have a similar cross-sectional shape and ground bearing pressures. Also, it is desirable to have the same shaped flat region touching the ground. Here the axle weight/tyre pressure ratio can be adjusted to ensure this. When the ground is not firm it may be more critical to model the penetration of the tyre into the ground. This is hard to predict from theory.

MONITORING REQUIREMENTS

Essential

Towing Force: This is the most critical parameter to monitor. With a two wheel buggy torques can be eliminated by a swivelling coupling. Many suitable transducers exist. The most common type employs a strain gauge ridge. Some preamplification may be required here as stress cells tend to have low voltage differential signals, initially this can be built in-house. System calibration is also necessary.

Vertical Towbar Force: Any weight taken by the towbar is weight releaved from the axle and thus should be compensated for. This requires another stress cell although (probably) compressive rather than tensile in nature. Both of these signals require a large degree of smoothing to eliminate the shockloads that result from unevenness. This may be accomplished at various stages: physically cushioning the shocks, filtering the analogue signal, in the analogue-digital conversion or by averaging readings in software.

Other Desirable Parameters

Vehicle Speed: It is desirable to perform the tests at a standardized speed thus it is logical to include a speed recorder.

Suspension: The roughness of the road is clearly a component of rolling resistance and the shock absorber system clearly absorbs kinetic

energy. It would thus be of interest to have some measure of roadway roughness and the energy absorbed by the shocks. The energy absorbed will be a function of the dynamic properties of the suspension system and the load and so will not be directly related to other vehicles. However this data will enable trends between variables to be investigated and provide an insight into the effect of roughness on rolling resistance. The rolling resistance due to unevenness is also probably speed dependent. Initially one would therefore be looking for a high rate of sampling of the roadway roughness and the energy absorbed by the suspension.

Gradient: This must be determined for the calculation of rolling resistance. This may be initially determined from surveying but it would be highly desirable to measure it with, for example, an inclinometer attached to the towbar. This will be affected by the roughness of the roadway and will require smoothing by techniques such as data averaging.

Tyre penetration: This is a parameter of interest and it is felt that eventually some method can be devised for determining it in a continuous fashion rather than by manual measurements.

Tyre Temperature and Dynamic Pressure

Tyre overheating and the resulting failure of the tyre is a serious problem in the mining industry. Therefore it is desirable to know to what extent a given road surface (or under-inflation of the tyre) is prone to cause heating in tyres. To monitor these factors requires both tyre temperature and pressure transducers.

Truck Position: To monitor the movements of a truck steering wheel is easily done. This combined with truck velocity data will provide information on the position of the truck within the mine site which can then be automatically plotted on a mine plan. This combined with the other data will, after computer processing, provide an immediate graphical presentation of the condition of the mine haulage roads with little demand on manpower for preparation.

The Data Acquisition System

The authors feel confident that a working system can be quickly built to measure the essential parameters using the existing lab "Polycorder"

and some homebrewed front end signal conditioning. A more desirable system, however, for the long term would be as follows:

A system based on an IBM compatible, probably with an 8086 processor and a "smart" data acquisition card. This would require a signal conditioning unit and suitable adaptors and protection to use a vehicles 12v power supply. It is expected that this would cost much less than $15K depending on how much of the system requires custom building.

Developing Equipment Factors

Having acquired "standard" rolling resistances for a number of cases it is desirable to correlate these measurements with the actual resistance experienced by various types of mobile mining equipment. This correlation will ensure that the best possible estimation can be entered into simulation calculations and programs. The correlation may be best done by back calculating from time trials or else, where available, from such truck towing experiments as exist. The following text discusses some examples of the possible areas of interest that may arise from this work.

Speed Factors: the speed of a vehicle determines the effect of the surface topography. The soil may react in a rate dependent (viscous) manner and there may be some dynamic effect on tyre penetration such as the "buoyancy" effect observed with skis. The effect of speed can be explored with the buggy, it is not clear a priori what effects will dominate.

Tyre Factors: Different tyre cross-sections, construction methods and tread, displace the soil differently and thus have different resistances.

Tyre Pressure: Tyre pressure determines the nature of the tyre/ground contact and under many conditions will closely equal the stress available to penetrate the ground and thus greatly effect depth of penetration. Current practices take this into account by using lower tyre pressures and vehicle payloads on soft ground.

Weight Factors: The overall axle weight is likely also to affect penetration and thus rolling resistance.

Power: The model considers wheels being towed. The stress distribution about the wheel is presumably different where the wheel is being used to drive a vehicle. Cornering or breaking will also affect the stress distribution.

Basic Research into Rolling Resistance

Various approaches may yield useful theoretical explanations of the data obtained:

Metallurgy and materials science yields two areas or interest; the related areas of indentation theory and plasticity.

The science of plasticity has its origin in the German metallurgical industry between the wars and was extensively used to understand the penetration of tanks by shells. Though in some ways it resembles elasticity theory in what it sets out to do it has generally been less successful. Elastic solutions to problems generate the expected stress field, plastic solutions also give the slip lines on which plastic slip has occurred. One often feels that the assumptions of material behaviour are too simple to use classical plasticity. This may well be the case here. For example it may often be the case that the material under the tyre suffers a permanent volume reduction, not allowed by theories designed to study effects in metals. A plastic analysis would show the flow of material under an advancing tyre for different shaped tyre and different axle loads. This may well be of interest.

The subject of indentation theory is a specialized branch of the mechanics of solids that finds applications in many diverse areas including mining. There has been a special effort to include unusually material properties using numerical methods. Unfortunately the literature is widely dispersed.

A second area of appropriate theory is the application of energy balance. Rolling resistance is a set of processes that remove kinetic energy from the truck. By analysing how much is absorbed by the various mechanism the measures taken to reduce this absorption may be prioritised.

Economic Models

It is hoped that the above approach would enable a much firmer grasp of the economic issues associated with rolling resistance and that these could be incorporated into a tool for designing maintenance programs. Such a tool would take into account the full cost of rolling resistance in terms of equipment efficiency, fuel costs, wear of trucks etc. as well as calculating the effect and cost of remedial measures such as grading, surfacing material, chemical stabilisers, water and the effect of weather.

CONCLUSION

This project would seem to meet the requirements of this laboratories new direction. It can achieve many of its goals quickly. With the exception of obtaining a suitable vehicle to tow the buggy (which may occur as part of the offices normal replacement policy) it is relatively cheap. By gathering data from a wide variety of mines it would provide exposure for the operations research group, and facilitate further involvement through, for example, the application of the data in simulation programs. The resulting instrumental buggy would be of potentially a service which could be operated on a cost - recovery basis. It is not restricted in use to coal mines but might be applied to a variety of off-road hualge problems.

It provides an excellent basis for further research into truck based sensors.

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